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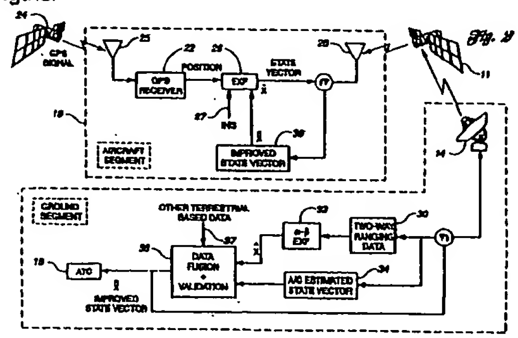
(54) Method and system for determining a position of a transceiver unit utilizing two-way ranging in a polystatic satellite configuration

(57) A method and system for determining a position of an object utilizes two-way ranging and polystatic techniques. A first communication transceiver (11) at a first known location provides a bidirectional communication path between the first communication transceiver (11) and the object (12) wherein the first communication transceiver (11) transmits a first ranging signal to the object (12) and the object (12) transmits a second ranging signal to the first communication transceiver (11) in response to the first ranging signal. The first communication transceiver (11) further provides a first unidirectional communication path between the first communication transceiver (11) and the object (12) wherein the first communication transceiver (11) performs one of transmitting a third ranging signal to the object (12) and receiving a fourth ranging signal from the object (12). A second communication transceiver (11) at a second known location provides a second unidirectional communication path between the second communication transceiver (11) and the object (12) wherein the second communication transceiver (11) performs one of transmitting a third ranging signal to the object (12) and receiving a fourth ranging signal from the object (12). A signal processor (14, 16) determines a first path length corresponding to a first time length of the bidirectional communication path, a second path length corresponding to a second time length of the first and second unidirectional communication paths, and the position of the object (12) based on the first and second known locations and the first and second path lengths.



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Description

Cross-Reference to Related Applications

This application is related to co-pending application entitled "Method and System for Determining a Position of a Target Vehicle Utilizing Two-Way Ranging," filed February 21, 1997 and is further related to co-pending application entitled "Method And System For Determining A Position of A Transceiver Unit Utilizing Two-Way Ranging in a Polystatic Satellite Configuration Including a Ground Radar," filed Feb. 21, 1997 .

Technical Field

This invention relates to methods and systems for determining a position of a transceiver unit, such as those provided on an airplane or a surface vehicle, utilizing two-way ranging through multiple satellites.

Background Art

Current Automatic Dependent Surveillance (ADS) technology, such as Global Positioning System (GPS), Wide Area Augmentation System (WAAS) or GLONASS, provides positioning information utilizing satellite transmissions. For example, the GPS, developed and deployed by the U.S. Department of Defense, consists of 24 satellites orbiting the earth twice a day at an altitude of 12,000 miles, as well as five ground stations to monitor and manage the satellite constellation. Using atomic clocks and location data, GPS satellites transmit continuous time and position information 24 hours a day to a GPS receiver, which listens to three or more satellites at once to determine the user's position. By measuring the time interval between the transmission and the reception of a satellite signal, the GPS receiver calculates the distance between the user and each satellite, and then uses the distance measurements of at least three satellites to arrive at a position.

Such systems, however, utilize one-way ranging in which an accurate, synchronized clock is required at each station. Any synchronization error or error regarding the location of one of the satellites results in an error in the determined position of the target vehicle. Thus, there is a need to provide very accurate position and velocity information with a high degree of integrity and reliability.

Disclosure Of The Invention

It is thus a general object of the present invention to provide a method and system for determining a position of an object, such as an airplane or a surface vehicle, utilizing two-way ranging in a polystatic satellite configuration to derive independent estimates of the transceiver's state vectors including position and velocity.

In carrying out the above object and other objects, features, and advantages of the present invention, a method is provided for determining a position of the object. The method includes the steps of transmitting a first ranging signal from a first known location to the position and transmitting a second ranging signal in response to the first ranging signal to the first known location. The method also includes the steps of transmitting a third ranging signal from a second known location to the position and transmitting a fourth ranging signal to a third known location in response to the third ranging signal. The method further includes the step of determining a first delay corresponding to a time difference between transmission of the first ranging signal and receipt of the second ranging signal. The method also includes the step of determining a second delay corresponding to a time difference between transmission of the third ranging signal and receipt of the fourth ranging signal. Finally, the method includes the step of determining the position of the object based on the first, second, and third known locations and the first and second delays.

In further carrying out the above object and other objects, features, and advantages of the present invention, a system is also provided for carrying out the steps of the above described method. The system includes a first communication transceiver at a first known location for providing a bidirectional communication path between the first communication transceiver and the object wherein the first communication transceiver transmits a first ranging signal to the object and the object transmits a second ranging signal to the first communication transceiver in response to the first ranging signal. The first communication transceiver further provides a first unidirectional communication path between the first communication transceiver and the object wherein the first communication transceiver performs one of transmitting a third ranging signal to the object and receiving a fourth ranging signal from the object. The system also includes a second communication transceiver at a second known location for providing a second unidirectional communication path between the second communication transceiver and the object wherein the second communication transceiver performs one of transmitting a third ranging signal to the object and receiving a fourth ranging signal from the object. The system further includes a signal processor for determining a first path length corresponding to a first time length of the bidirectional communication path, determining a second path length corresponding to a second time length of the first and second unidirectional communication paths, and determining the position of the object based on the first and second known locations and the first and second path lengths.

The above object and other objects, features and advantages of the present invention are readily apparent from the following detailed description of the best mode for carrying out the invention when taken in connection with the accompanying drawings.

Brief Description Of The Drawings

FIGURE 1 is a diagrammatic representation illustrating a communication system employing the method and apparatus of the present invention;

FIGURE 2 is a block diagram of the aircraft segment and the ground segment included in the system shown in Figure 1;

FIGURE 3 is a block diagram of a preferred transmitter and a preferred receiver for the traffic controller station used in the system of Figure 1; and

FIGURE 4 is a block diagram of a preferred transmitter and a preferred receiver for a vehicle in the system of Figure 1.

Best Modes For Carrying Out The Invention

Referring first to Figure 1, a communication system 10 with a typical geometry for practicing the present invention is diagrammatically illustrated. In general, the system 10 includes a target object 12, represented by an aircraft 12 in the preferred embodiment, although Earth-bound vehicles are also trackable with the present invention. A plurality of communication satellites 11 through which aircraft 12 communicates with at least one traffic controller station 16 via a satellite ground station 14 are within the field of view of aircraft 12 at a given time.

Communication satellites 11 are preferably in multiple planes using Low Earth Orbit (LEO) satellite constellations and/or Medium Earth Orbit (MEO) satellite constellations such as Iridium, Intermediate Circular Orbit (ICO), Teladesic or Globalstar. In addition, a Geosynchronous Earth Orbit (GEO) satellite constellation may also be used in conjunction with the LEO and/or MEO satellite constellations. The planned ICO configuration with ten to twelve satellites in two planes is adequate to implement the position location and tracking of aircraft 12 for navigation and landings (up to Category I) while providing the necessary global coverage.

Multiple dynamic communication links between aircraft 12 and a satellite ground station 14 are achieved via the plurality of communication satellites 11, which are then utilized to derive independent estimates of the positions and velocities (state vectors) of aircraft 12. To obtain more accuracy and flexibility, the present invention employs a polystatic configuration. A polystatic configuration consists of several transceivers at separated locations, which cooperate with each other. The transceivers may be stationary or moving.

In a monostatic configuration, the forward and return ranging signals propagate through the same link. As such, the equal range locations of the measurement are confined to a spherical surface centered on the relay satellite position with a radius (range) equal to a distance between aircraft 12 and the relay satellite. By utilizing polystatic techniques, in which the forward and return ranging signals propagate through different satellites, the equal range locations of the measurement are confined to an ellipsoidal surface. The two foci are located at the satellite positions so that the sum of the distances between aircraft 12 and the two satellites 11 is a constant.

Satellite ground station 14, such as a Satellite Access Node (SAN), transmits a ranging signal to a targeted object, such as aircraft 12, via one of communication satellites 11. Aircraft 12 then retransmits a data message back down to ground station 14 via the same communication satellite 11 or a different one or set of communication satellites 11 utilizing polystatic techniques. Preferably, traffic controller station 16 informs the aircraft 12 of which return link strategy to employ prior to initiation of the two-way ranging. Each ranging signal transmitted by satellite ground station 14 may be forwarded to the same satellite 11 and then the retransmitted data messages from aircraft 12 may be forwarded through different satellites 11. Thus, the forward and return ranging signals can propagate through various links via different satellites, i.e., for each forward path, there are N return paths available for a total of NxN possible links.

The positions in space of communication satellites 11 are known so that corresponding ranges R_1, R_2, and R_3 between each of communication satellites 11 and satellite ground station 14 are known. However, ranges R_1, R_2 and R_3 can be calibrated over time to obtain a more accurate measurement. The links R_4, R_5, and R_6 are then employed to determine the state vectors by two-way ranging from satellite ground station 14 to aircraft 12. The time difference between transmission of the ranging signal by the satellite ground station 14 and receipt by the satellite ground station 14 of the responding ranging signal from aircraft 12 is used in determining ranges R_4, R_5, and R_6.

In determining the position and velocity of aircraft 12, the present invention may be utilized in conjunction with GPS. When GPS signals are available, the GPS signals are used to derive the aircraft state vector which is then transmitted to traffic controller station 16, such as an Air Traffic Controller (ATC) facility, via communication satellites 11 and satellite ground station 14. Preferably, the ATC facility 16 has signal processing capability. Alternatively, the signal processing capability may be located at satellite ground station 14. Simultaneously, ranging signals are sent by satellite ground station 14 via communication satellites 11 to a targeted aircraft, such as aircraft 12. Aircraft 12 then retransmits this ranging signal on a return link back to satellite ground station 14. The returned two-way ranging signals are detected and tracked in time and frequency by satellite ground station 14. Measured time and frequency values from multiple satellite links are compared to predicted values. Improved estimation of the aircraft state vectors

is accomplished through data fusion of the two independent measurements, i.e, the GPS measurement and the two-way ranging measurement. The updated aircraft state vectors are then transmitted to aircraft 12.

The time stamps through various forward links arrive at aircraft 12 in different time slots. It is possible to allow fixed processing delays to multiplex the time stamps together, and then transmit the multiplexed ranging signal through different return links simultaneously or sequentially. However, it is also possible to transmit the multiplexed signal through a single return link to save return link space assets when needed. Similarly, the present invention is flexible enough to save forward link assets also. In addition, it is possible to use ICO satellites either as forward or as return link relays (not both) and to utilize other (GEO, MEO or LEO) mobile satellites as the complementary link relays.

Turning now to Figure 2 there are shown simplified block diagrams of both an aircraft segment 18 and a ground segment 20 of the present invention. Aircraft segment 18 includes a conventional GPS receiver 22 for receiving GPS signals from a GPS satellite 24 via an antenna 25. GPS receiver 22 sends a position signal to a conventional Extended Kalman-Filter (EKF) 26 which tracks the position signal as a state vector. An optional input 27 to EKF 26 is a signal from an Inertial Navigation System (INS), such as a conventional mechanical gyro system which monitors the distance traveled by aircraft 12 from a predetermined position.

Aircraft 12 receives the ranging signals from communication satellites 11 via a second antenna 28. Second antenna 28 is preferably a retrodirective antenna implemented with a Butler matrix, a low-profile digital beam former, and Wavelet-based Finite-Impulse-Response (WFIR) Signal processing. The retrodirective antenna measures the direction of the received signal from communication satellite 11 and automatically transmits the return signal back to the same or a different one of communication satellites 11. The Butler matrix implements a Fourier transform forming a set of nearly orthogonal beams covering the field-of-view and is a relatively inexpensive approach to realizing a retrodirective antenna. The low-profile digital beam former array lends itself to a thin conformal array configuration which is preferred for aircraft installation. Optionally, a tracking antenna can be used in place of the retrodirective antenna which consists of either an electronically or mechanically steered antenna driven by a monopulse, step-scanned, or conically-scanned tracking loop.

In order to utilize polystatic techniques in the present invention, a digital implementation of the Butler matrix is also preferred, such as a conjugate gradient digital beam former, in order to memorize the phase gradients of signals from various communication satellites 11, i.e, the direction or the incoming signals, and to apply proper phase conjugations to the outgoing signals so that the outgoing signals are directed to the appropriate communication satellites 11.

The data between aircraft segment 18 and ground segment 20 can be combined with the unique ranging code signal in one of several ways: 1) Overlaying a Auslander-Barbano (AB) Code Division Multiple Access (CDMA) tracking code on the communication link channels as low-level Additive White Gaussian Noise (AWGN), thermal noise-like signals which slightly raise the thermal noise floor; 2) Modulating the communication data with the AB CDMA ranging code and sent as a single waveform, as shown in Figure 3; and 3) Separating the ranging links from data links. In the preferred embodiment shown in Figure 3, ATC facility 16 transmits data which is modulated by a WFIR waveform with a unique AB ranging code assigned to each aircraft being tracked in the particular time slot. WFIR modulation enables the ranging signals to have variable resolution in addition to variable length. The waveform specifically provides a means to transmit a relatively wide-band WFIR ranging waveform over a group of narrow-band communication satellite channels, simultaneously or sequentially, and supports simultaneous ranging/doppler measurements and data demodulation.

The two-way ranging data 30 is sent to ground segment 20 via satellite ground station 14. Two-way ranging data 30 is used to drive a dual alpha-beta (α-β)/EKF tracking loop 32 wherein the fast α-β loop tracks the AB CDMA code in communication coordinates, and the slow EKF tracks the target aircraft in Earth Centered Inertial (ECI) coordinates to provide a unique preferred tracking architecture with low-complexity, high accuracy, and high integrity with fast-response valid-track metrics, and the ability to track out total-electron-content (TEC) induced waveform transmission range and doppler offsets.

The α-β loop is a relatively fast pair of time and frequency tracking loops which measure and smooth the received two-way ranging signals during each access. The four-dimensional state vector Z for the α-β loop consists of the timing offset, time drift, frequency offset and frequency drift. Time drift refers to clock drift whereas frequency offset refers to doppler shift due to link motion plus TEC. The state vector X for the EKF loop has 11 components consisting of the three-dimensional ECI position coordinates, velocity, acceleration, and the ranging plus doppler coordinates associated with ionospherical TEC effects.

Based on the α-β observation data from a previous access, the EFK loop predicts its state X_k at the state transition time k*T, where T is the update interval for the EKF. This state is mapped into the corresponding predicted state Z_k of the α-β loop. During the access slot time ΔT, the α-β loop generates a smoothed state Z_k which is then used by the EKF to smooth the predicted state to generate smoothed the state X_k. This allows the EKF to predict the state X_{k+1} at (k+1)*T. This procedure is repeated for the next access.

The predicted state vector from dual α-β/EKF tracking loop 32 and the estimated state vector 34 from air-

craft 12 are transmitted to a processor 36 which performs data fusion and validation between the two independent measurements to obtain an improved state vector estimation. Processor 36 also receives other terrestrial based data 37, such as position of satellite ground station 14 and position of communication satellites 11. The improved state vector estimation is forwarded to ATC facility 16 which then transmits this information to aircraft 12. The improved state vector estimation 38 received by aircraft 12 is processed by EKF 26 to generate a new state vector.

Referring now to Figure 3, additional details of the receiver and transmitter used in traffic controller station 16 are shown comprising a transmitter 40 and a receiver 42. Satellite ground station 14 transmits data which is modulated by a wavelet-based finite impulse response (WFIR) waveform with a unique AB ranging code assigned to each aircraft 12 being tracked in the access time slot. The TDMA data to the targeted aircraft is modulated by the N-chip AB code sequence, unsampled by the WFIR sample rate M, and added with signals to other aircraft sharing the same access slot. The summed output is filtered by a wideband WFIR filter with overlaid envelope of the AB ranging waveforms. A bank of narrowband WFIR filters channelizes the wideband waveform into a set of narrowband waveforms which are compatible with the satellite communication channels such as ICO.

The receive processing at satellite ground station 14 is shown at 42. The baseband signal from the digitizer, shown as an analog-to-digital (A/D) function and an in-phase-quadrature (I/Q) function which may be combined is detected by a bank of narrowband (NB) WFIR filters matched to the ICO communication channels. The outputs are used to perform reconstruction of the wideband WFIR ranging signal for each aircraft. This reconstructed wideband WFIR waveform is then detected by on-time, early, and late correlators. The ranging time and data from each aircraft is recovered by separate processing which performs the AB CDMA despreading, acquisition, tracking, time recovery, and data recovery.

As best shown in Figure 4, aircraft receiver/transmitter 44 preferably includes a retro-directive antenna 46. A Butler matrix, low profile digital beam form (DBF), and WFIR signal processing are preferably employed. Retrodirective antenna 46 measures the direction of the received signal from satellite 11, and automatically transmits the return signal back to an appropriate satellite 11. The Butler matrix implements a Fourier transform forming a set of nearly orthogonal beams covering the field of view, and has been proven to be a relatively inexpensive approach to realize a retrodirective antenna. The low profile DBF array lends itself to a thin conformal array configuration which is preferred for aircraft installation. The implementation technique eliminates the need for an expensive tracking antenna on the aircraft which usually consists of either an electronically or a mechanically steered antenna driven by a monopulse, step-scanned, or conically-scanned tracking loop.

The present invention works in many multiple-satellite constellations or combinations of multiple constellations. The present invention improves position and velocity accuracy in tracking a target transceiver unit and provides a simple method to access more resources from space assets other than one constellation alone. Even if the GPS or GLONASS systems malfunction, the present invention still provides adequate position location and tracking measurements for global air traffic control without complex clock and processing requirements.

While the best modes for carrying out the invention have been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.

Claims

1. A method for determining a position of an object (12), the method comprising:

   transmitting a first ranging signal from a first known location to the object (12);
   transmitting a second ranging signal to the first known location in response to the first ranging signal;
   determining a first delay corresponding to a time difference between transmission of the first ranging signal and receipt of the second ranging signal;
   transmitting a third ranging signal from a second known location to the object (12); characterized by
   said method utilizing two-way ranging, and further comprising
   transmitting a fourth ranging signal to a third known location different from the second known location in response to the third ranging signal;
   determining a second delay corresponding to a time difference between transmission of the third ranging signal and receipt of the fourth ranging signal; and
   determining the position of the object (12) based on the first, second, and third known locations and the first and second delays.

2. The method of claim 1, characterized in that the second known location is the same as the first known location and wherein the third known location is different from the first known location.

3. The method of claim 2, characterized by:

transmitting a fifth ranging signal from the first known location to the object (12);
transmitting a sixth ranging signal to a fourth known location different from the first and third known locations in response to the fifth ranging signal;
determining a third delay corresponding to the time difference between transmission of the fifth ranging signal and receipt of the sixth ranging signal; and
determining the position of the object (12) based on the first, third and fourth known locations and the first, second and third delays.

4. The method of claim 1, characterized in that the second known location is different from the first known location and wherein the third known location is the same as the first known location.

5. The method of claim 4, characterized by:

transmitting a fifth ranging signal from a fourth known location different from the first and third known locations to the object (12);
transmitting a sixth ranging signal to the first known location in response to the fifth ranging signal;
determining a third delay corresponding to a time difference between transmission of the fifth ranging signal and receipt of the sixth ranging signal; and
determining the position of the object (12) based on the first, third and fourth known locations and the first, second and third delays.

6. A system for determining a position of an object (12), the system comprising:

a first communication transceiver (11) at a first known location for providing a bidirectional communication path between the first communication transceiver (11) and the object (12) wherein the first communication transceiver (11) transmits a first ranging signal to the object (12) and the object (12) transmits a second ranging signal to the first communication transceiver (11) in response to the first ranging signal, and the first communication transceiver (11) further for providing a first unidirectional communication path between the first communication transceiver (11) and the object (12) wherein the first communication transceiver (11) performs one of transmitting a third ranging signal to the object (12) and receiving a fourth ranging signal from the object (12); and
a signal processor (14,16) for determining a first path length corresponding to a first time length of the bidirectional communication path,

characterized by said system utilizing two-way ranging, and further comprising a second communication transceiver (11) at a second known location for providing a second unidirectional communication path between the second communication transceiver (11) and the object (12) wherein the second communication transceiver (11) performs one of transmitting a third ranging signal to the object (12) and receiving a fourth ranging signal from the object (12), said processor (14, 16) determining a second path length corresponding to a second time length of the first and second unidirectional communication paths, and determining the position of the object (12) based on the first and second known locations and the first and second path lengths.

7. The system of claim 6, characterized in that the first unidirectional communication path is from the first communication transceiver (11) to the object (12) so that the first communication transceiver (11) transmits the third ranging signal to the object (12) and wherein the second unidirectional communication path is from the object (12) to the second communication transceiver (11) so that the object (12) transmits the fourth ranging signal to the second communication transceiver (11) in response to the third ranging signal.

8. The system of claim 6, characterized in that the first unidirectional communication path is from the object (12) to the first communication transceiver (11) so that the first communication transceiver (11) receives the fourth ranging signal in response to the third ranging signal and wherein the second unidirectional communication path is from the second communication transceiver to the object (12) so that the second communication transceiver (11) transmits the third ranging signal to the object (12).

9. The system of claim 6 or 7, characterized by:

a third communication transceiver (11) at a third known location for providing a third unidirectional communication path between the third communication transceiver (11) and the object (12) wherein the first communication transceiver (11) transmits a fifth ranging signal to the object (12) and the third communication transceiver (11) receives a sixth ranging signal from the object (12) in response to the fifth ranging signal; and

wherein the signal processor (14,16) determines a third path length corresponding to a third time length of the first and third unidirectional communication paths and determines the position of the object (12) based on the first,

second and third known locations and the first, second and third path lengths.

10. The system of claim 6 or 8, characterized by:

a third communication transceiver (11) at a third known location for providing a third unidirectional communication path between the third communication transceiver (11) and the object (12) wherein the third communication transceiver (11) transmits a fifth ranging signal to the object (12) and the first communication transceiver (11) receives a sixth ranging signal from the object (12) in response to the fifth ranging signal; and

wherein the signal processor (14,16) determines a third path length corresponding to a third time length of the first and third unidirectional communication paths and determines the position of the object (12) based on the first, second and third known locations and the first, second and third path lengths.

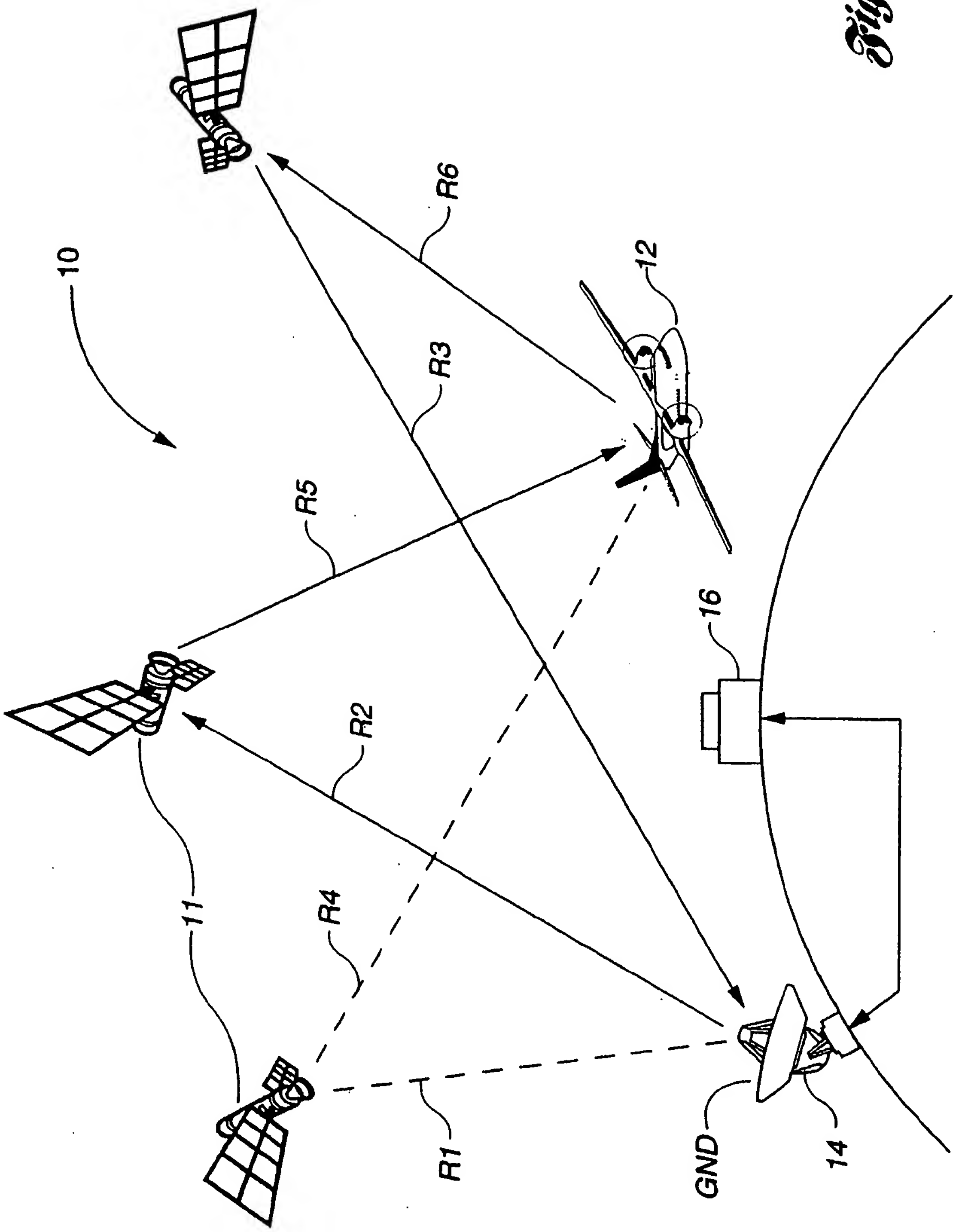
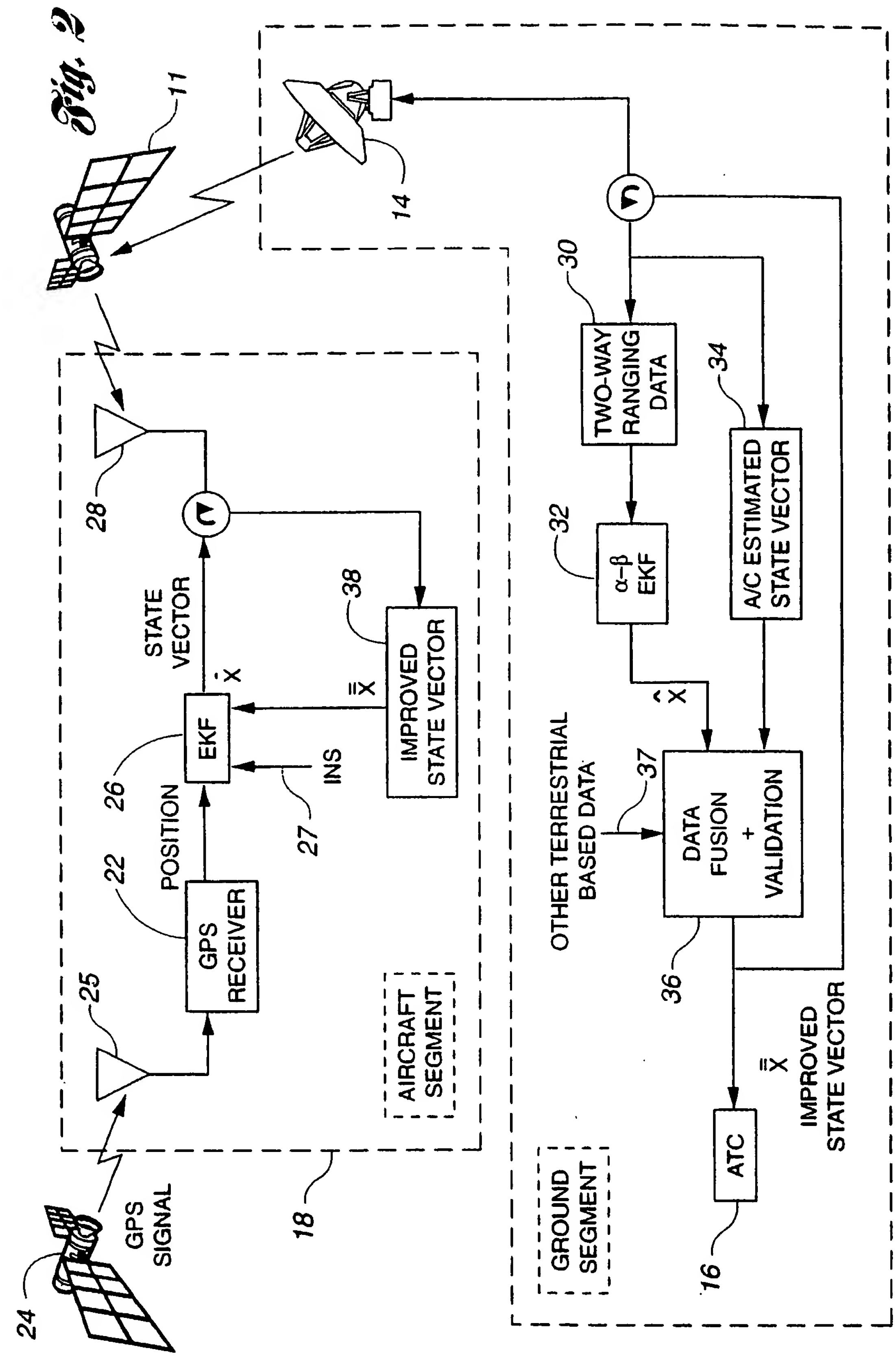


Fig. 1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GPS SIGNAL
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GPS RECEIVER
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INS
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STATE VECTOR
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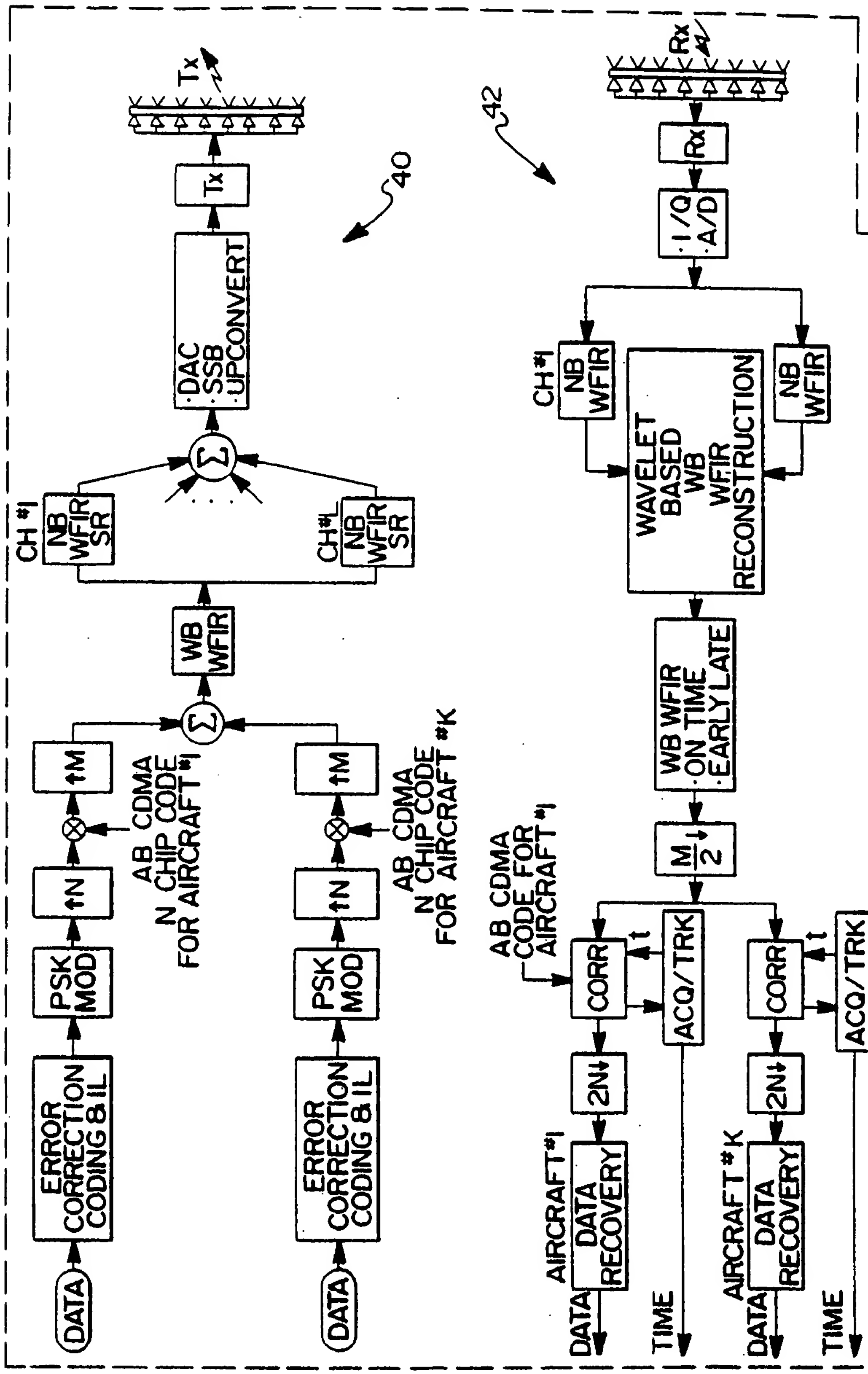
38
IMPROVED STATE VECTOR
AIRCRAFT SEGMENT
30
TWO-WAY RANGING DATA
32
α–β EKF
34
A/C ESTIMATED STATE VECTOR
OTHER TERRESTRIAL BASED DATA
37
DATA FUSION + VALIDATION
36
ATC
16
IMPROVED STATE VECTOR
GROUND SEGMENT

Fig. 2



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AB CDMA N CHIP CODE FOR AIRCRAFT #K
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CH #L NB WFIR SR
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Tx
40
42
Rx
I/Q A/D
CH #1 NB WFIR
NB WFIR
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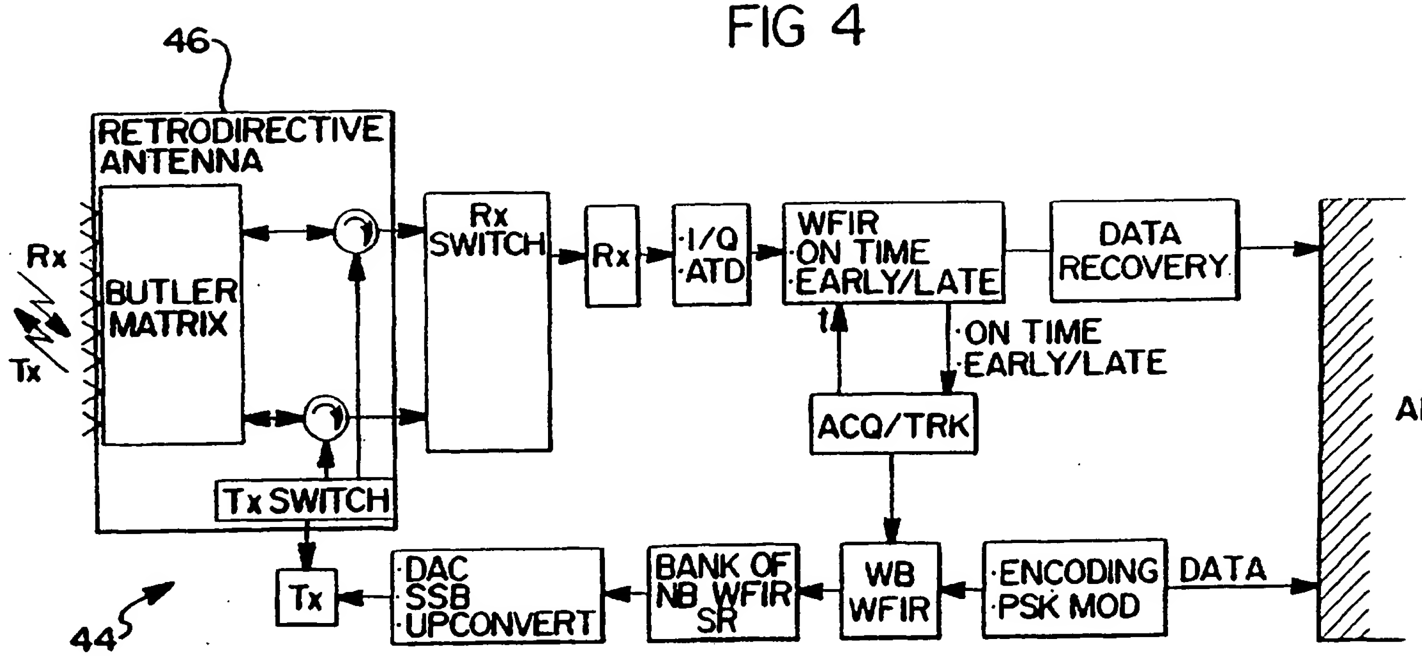
FIG 3

FIG 4


46
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